SCHOOL OF MECHANICAL ENGINEERING

Department of Vehicle Engineering

RESEARCH OF NORTH POLE AMPHIBIOUS VEHICLE’S TECHNOLOGIES AND POWERTRAIN SIMULATION

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Abstract

The aim of this master's thesis is to provide a useful framework for upcoming researches about amphibious vehicles designed for the North Pole. This thesis is a brief introduction to the North Pole Amphibious Vehicles, which consists in studying the main requirements of this kind of vehicle. Thus, the research about amphibious vehicle technologies is done on the state-of-art and different powertrain systems and configurations are studied.

In this project, a 3D design of an amphibious vehicle and its flow simulation were created with Solidworks in order to calculate the longitudinal parameters of the vehicle.

The powertrain system has been chosen following an analysis of conventional, electric and hybrid powertrains, so as to determine which system has a better performance at the North Pole.

Different powertrain configurations have been modelled in Matlab Simulink following the mathematical equations that describe the components or using the Powertrain Blockset offered by Matlab. The software simulates the whole powertrain dynamics in conjunction. The results obtained by the simulation were used to compare the 4WD and 6WD powertrains in order to find out which are the most suitable.

Contents

1. Introduction

The North Pole (also known as Geographic North Pole or Terrestrial North Pole) is one of the points of the earth's surface that coincide with its rotation axis, the opposite one is called South Pole.

The North Pole is situated at Arctic Ocean, where the sea is almost constantly covered by a thick layer of ice. The thickness of these layers can reach 5 meters in the nearest areas to North Pole because of its climate. In winter, the temperatures can range from -50 to -13^{o}C, with an average of -31^{o}C, and in summer, the average is around 0^{o}C with the highest recorded temperature being 13^{o}C [1].

Currently, the Arctic countries that surround the North Pole are the Russian Federation, Norway, Denmark (Greenland), Canada and the United Stated (Alaska). However, no country owns the North Pole or the region of the Arctic Ocean that surrounds this point, since it is under international law.

The fauna of the North Pole is quite limited, the animals that live in such cold places are Polar bears, ringed seals and Arctic foxes. Some birds seen at the North Pole are Snow bunting, Northern fulmar and Black-legged kittiwake [2]. However, there are many unidentified creatures underwater [3] since the thick layer of ice does not allow an easy exploration. In addition, the harsh surface conditions, a mixture of ice, water and snow, make it really difficult to access those areas using conventional vehicles such as boats or cars. Therefore, either an icebreaker or an aircraft is needed.

During the history of humankind, there have been a lot of expeditions to the North Pole, some of them resulting in tragedies while others were successful. Before the 21st century, many ways to arrive to the North Pole had been tried, e.g. Icebreaker, helicopter, etc. Nevertheless, during the past few years, the Russians achieved a new way to arrive to the Pole. In 2009, the Russians reached the North Pole with two custom-built 6x6 low-pressure-tire ATVs (Yemelya-1 and Yemelya-2), achieving the recognition to be the first trip from land to the Geographical North Pole [2].

2. Objectives

Due to climate change and global warming, huge glaciers and ice grounds in the Arctic are rapidly melting. This fact is opening multiples choices to the world, such as new shipping routes, transport routes, etc. Economically speaking, this could involve important benefits because of shorter shipping times.

On the other hand, recently, the high oil prices and the fast melting of the ice are bringing the attention of petroleum industries from countries surrounding the Arctic Ocean and even countries such as China, India and Japan, because according to an USGS publication, the Arctic is estimated to contain between 44 and 157 billion barrels of recoverable oil [4].

In order to exploit the North Pole region, great powers like Russia, China and the United States are seeking new resources to take advantage of and, consequently, considering the option to explore the North Pole [5]. In spite of the existence of the Ice-breaker, an expensive resource, there is a need for other kinds of vehicles that allow to take cheap trips. This is why the amphibious is under research and could be a very useful resource.

Hence, with the final purpose of pleasing the current demand, the objectives of this master's thesis are:

- Do a research about amphibious vehicles.
- Do a research about the different technologies required in amphibious vehicles.
- Design the amphibious vehicles with the main requirements.
- Select a suitable powertrain configuration for the North Pole conditions.

3. Amphibious vehicles - State of the Art

Currently, the world has many different kinds of weird artefacts created as prototypes by amateurs or big companies. At present, we do not have a relevant amount of information regarding amphibious vehicles. Most of the information that we can find is about military war amphibious vehicles.

3.1. Types of amphibious vehicles

The different types of amphibious vehicles are:

3.1.1. Wheeled

Cycles

Figure 1. Cyclomer, Paris 1932

A human powered amphibious vehicle, equipped with floats for buoyancy.

ATVs (All-Terrain Vehicles)

Figure 2. Sherp ATV

The AATVs (Amphibious All-Terrain Vehicles) are non-air cushioned vehicles propelled by the wheels with a maximum speed, usually, over 40 km/h.
This kind of vehicle uses a watertight body to get the needed buoyancy. Usually, the AATV is a small, lightweight vehicle without suspension or steering wheels. The direction of the vehicle is controlled by changing the speed of the wheels of each side.
The first fast AATV is named Long-awaited-Quadski made by Gibbs Amphibians, and it is able to reach 75km/h.

Cars

Amphibious cars were originated in 1900, but the Second World War was the main incentive for developing these kinds of vehicles. Most of them use a combination of wheel-traction and a propeller.

The most famous vehicles are:

Figure 3. Schwimmwagen

Schwimmwagen (Germany, 1942): Small 4x4 Jeep, designed by Porsche.

Figure 4. Amphi-Ranger

Amphi-Ranger (Germany, 1985): The most capable post-war car, hull built by aluminium alloy (AlMg2) and very resistant in sea conditions.

Figure 5. Amphicar

Amphicar (Germany, 1961): The most successful amphibious car produced since the 60's to date because of its aesthetic and similarity to a conventional car.

Figure 6. Gibbs Aquada

Gibbs Aquada (New Zealand, 2003): Only fifty Aquadas were built in the 2000's, but it was a success because of its capability to reach high speeds on water.

Figure 7. WaterCar Python

Python (US, 2010): It is just a prototype but this car is the fastest amphibious car in the world according to the Guinness Worlds Record.

Boats

Figure 8. Profile Boats 635H

Marine vehicles enabled to drive on land. The main characteristic of the amphibious boat is the conventional boat design, just adding retractable wheels. This kind of vehicles are usually fast on aquatic environments and slow on land environments.

Oyster boats

Figure 9. Oyster boat

Amphibious boats specially designed for mussels and oysters' areas, made of aluminium. These boats can run through the wheels or by the propeller, depending the tide level.

Trucks

Figure 10. DUKW

Amphibian trucks were very successful vehicles in WWII due to its big carrying capabilities. In the wars, these trucks are used as suppliers, launched from the warcrafts, to supply material to beachheads.

Armoured vehicles

Figure 11. Panhard VBL

This group of vehicles is composed by armoured personnel carriers, tanks and amphibious warfare ships. These vehicles are propelled by waterjets and wheel-traction.

3.1.2. Tracked

Yachts

Figure 12. Iguana yacht

This kind of vehicle is very similar to amphibious boats, the unique difference is that instead of wheels, the boat is equipped with tracks, which allows a better traction over land than wheels.

Armoured

Figure 13. Sprut-SDM1

Amphibious armoured vehicles are principally used on land. Nevertheless, some of them have amphibious characteristics. It is mainly used by marine corps.

On water, these vehicles can be powered by hydrojets or by their own tracks.

Multi-units

Figure 14. Hagglunds Bv206

An all-terrain vehicle that has two different compartments. Each compartment is powered by an independent track; this makes a multi-unit vehicle much more robust on smooth terrains than a single-unit.

3.1.3. Deep fording

Figure 15. Deep-fording tank

The deep fording is a military vehicle which is able to drive underwater by using an entirely waterproof hull. Many of them are equipped with a long tube as commander's hatch to allow the submergence or as snorkel.

3.1.4. Hovercraft

Figure 16. Hovercraft

Hovercrafts are air cushioned vehicles (ACVs) that can hover over land and travel over water. The ability of hovering is thanks to the skirt that surrounds the base of the craft. This skirt is filled with pressurized air and the air is ejected from the bottom of the ship, making it lift.
ACVs are high speed vehicles over water and allow to make the transition between land and water without stopping the vehicle.

3.2. Amphibious vehicles technologies research

As mentioned before, currently, there is not a lot of information about amphibious vehicles, most of the researches are about military amphibious vehicles. Using this information, we will analyse the state-of-art of amphibious vehicles.

3.2.1. Miscellaneous components

From a mechanical viewpoint, the components of amphibious vehicles can be divided into three different groups:

- Structure
- Powertrain
- Suspension

The most important groups to focus on for the amphibious vehicle design are structure and powertrain. Hence, the technologies of different amphibious vehicles will be shown below.

3.2.1.1. Structure

In the case of the armoured amphibious vehicle, one of the biggest problems is the water collapse when this is crossing a river, lake, and so on, with a high speed, because this can produce the swamp of the vehicle. To avoid the water collapse of the vehicle and to improve the capability of driving with higher speed over water, there are two options:

1. Adding a head plate. The head plate is just a plate, flat-form or V-form, installed on the bow of the ship with a higher height than the vessel's draft line, as is shown in Figure 17.
2. Changing the bow design of the vehicle, using a design similar to boats.

Figure 17. Armoured vehicle with head plate in the bow

The inconvenient of the head plate is the increase of resistance that is produced over the vehicle. To offset this resistance, more power is needed, i.e. the vehicle with a head plate activated will need more power to reach a specific speed than a vehicle without head plate [6].

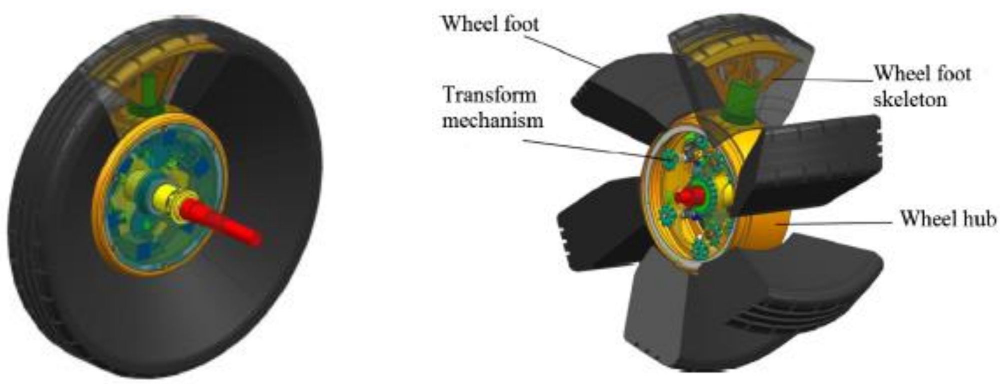
3.2.1.2. Powertrain

Another issue of All-Terrain Vehicles is the low traction of wheeled vehicles in smooth surfaces such as snow, mud or icy roads. Currently, there are many electronical-mechanical methods to avoid losing control of the vehicle (Traction Control System, Anti-Slip Regulation, Anti-lock Braking System, etc.). There are also snow tires that improve the traction in snow terrains considerably. However, these solutions are not enough because better traction on the ground is needed in order to reach the highest efficiency.

The Department of Automobile Engineering of Beihang University wanted to do further research and in 2016 they designed and developed a possible solution, a new transformable wheel for amphibious all-terrain vehicles (A-ATV), as is shown in Figure 18.

According to the report of the wheel designed by Beihang University, with the results obtained on the kinematic and the dynamic simulations, the wheel is feasible and could be a prominent improvement for off-road vehicles [7].

On the other hand, the transformable wheel in its unfolded state could be used as paddles in the water, avoiding the need of propellers, i.e. the amphibious vehicle could work properly with just one engine. Nevertheless, the speed will be slow.



(a) Folded wheel (b) Unfolded wheel

Figure 18. Transformable wheel designed by Beihang University [7].

Another solution to improve the traction consists in low-pressure tires. This kind of tires permit the vehicle to carry the same load with quite lower air pressure than conventional tires [8]. Low-pressure tires are very useful for off-road vehicles since they provide a good traction on icy lands, snow, mud or sand soils [9] [10]. This solution was adopted by Yemelya (Figure 19), the first amphibious vehicles to arrive from land to the North Pole, also adopted by the Sherp ATV and by Avtoros Shaman 8x8. More information in the following section.

3.2.2. Yemelya

Figure 19. Yemelya Amphibious vehicle

As stated in the last section, the Yemelya was the first vehicle to arrive to the North Pole from land. Therefore, seeing that this All-Terrain Amphibious Vehicle (shown in Figure 19) was a success, let's see its specifications [11]:

Yemelya is equipped with six wheels, a diameter of 1,30 meters, dressed with special low-pressure tires produced in China. Each wheel is mounted on independent suspensions (450 mm free travel). The watertight body is fully made of aluminium. The powertrain of the vehicle is equipped with two driveshaft that deliver torque from the engine to the locking differentials of the front and middle axle (rear differential is dependent of the middle axle), the engine (2.0 L Toyota 3C diesel), the electrical components, transmission (5 manual-speed), etc. These components are assembled inside the watertight body. That is to say, Yemelya is a vehicle allowed to drive in salty sea water.

The gross weight of the vehicle is 1450 kg and it is able to reach a max. speed of 55 km/h (on paved roads) and with its huge spinning wheels it is capable of propelling at the speed of 2-3 km/h on the water.

3.2.3. Sherp ATV

The Sherp ATV (Figure 2), equipped with a 1,5L Diesel engine and 5 manual-speed transmission, is an all-terrain vehicle with an impressive off-road performance. Its small size and its four huge wheels (1,60 meters of diameter) make it able to overcome boulders, fallen trees, deep snow, etc. Furthermore, due to the four low pressure tires and the watertight body, made of aluminium in order to optimise the weight of the vehicle, the vehicle has a high buoyancy and allows it to float and move over the water.

The dry weight of this vehicle is 1600kg, and combining it with the 44HP of the engine, the ATV can reach almost 40km/h in dry terrain. Otherwise, over the water, the huge wheels with paddles can propel the ATV with a maximum speed of 6km/h [12].

3.2.4. Avtoros Shaman

The Avtoros is an amphibious vehicle of big dimensions, equipped with 8 wheels (1,20 meters of diameter) that allows up to 12 people. According to its manufacturer, the Shaman is able to cross dirt, snow or marshes. That is to say, the Shaman is the perfect vehicle for people who love hunting and fishing in any season of the year.

On the other hand, this ATV has a great manoeuvrability and stability on the road due to its innovative steering system that affords three handling options: front wheels, front and rear wheels, and front and rear wheels with an opposite gyre.

The 3.0L Diesel engine that generates 176HP, the 6 manual-speed transmission and its 4800kg curb weight allow the vehicle to reach a maximum speed of 70km/h in terrain. Otherwise, on water, the maximum speed is just 2km/h. The drawback of the high power of this vehicle is its fuel consumption, Avtoros needs an average of 25L per 100km. In this case, a big fuel tank is needed to satisfy the high consumption and afford it to drive for hours on end [13].

4. Requirements

Once we have done an initial research about the different amphibious vehicles and their different technologies, it is possible to know what the requirements for a North Pole amphibious vehicle are:

- The vehicle should have a good ground clearance to cross any obstacle.
- The vehicle hull should be watertight to allow the buoyancy of the vehicle.
- The total weight of the vehicle should be as light as possible to facilitate the buoyancy.
- The commander hatch should be elevated and watertight to allow a good point of view and avoid the entrance of water inside the vehicle [6].
- Due to the big surface of the Arctic Circle, an amphibious vehicle bound to the North Pole should have a big capacity for provisions like food, research equipment, etc.
- For the same reason as the previous point, the vehicle should have a big autonomy.
- The Arctic is a place full of snow and water, so the vehicle should be ready to drive in these conditions. Therefore, the vehicle wheels should provide a good traction on that kind of ground.
- The vehicle should provide a high thrust at low speeds for the manoeuvrability [6].
- The Arctic also has some areas with water where the vehicle will need to use its buoyancy skills. To ensure a good buoyancy, wheels of bigger size would be needed.
- In water conditions, to avoid the water collapse and the swamp of the vehicle, the bow of the vehicle should have a similar design as boats (tilted).
- The mass centre of the vehicle should stay in the middle point of the vehicle to provide good stability on water.
- The drivetrain should be isolated from the salty sea water to avoid the corrosion of the components.
- The exhaust/intake of the engine should be dry at all times [6].
- The interior of the vehicle should be thermally insulated.
- Cavitation avoidance for good maintenance [6].

5. Powertrain

The powertrain of a vehicle comprises the main components that generate power and send the power to the road. These components include the engine and the drivetrain [14].

The drivetrain is composed by many elements which are in charge of transmitting the engine's power to the drive wheels. According to *Bosch Electronic automotive handbook* [15], these elements must perform the following functions:

- Remaining always stationary.
- Achieving the transition from stationary to mobile state of the vehicle.
- Converting the torque and rotational speed of the engine.
- Providing backward and forward motion.
- Regulating the wheels-speed variation in curves.
- Keeping the engine within a range on the operating curve where the vehicle gets the minimum fuel consumption and exhaust emissions.

The elements that make it possible to comply with the functions described previously, are:

- Clutch. This component allows to connect and disconnect the rotational speed of the engine with the drivetrain.
- Transmission (gearbox). This modifies the rotational speed and torque of the engine, adapting them to the tractive requirements of the vehicle.
- Differential. This component makes the different speeds of the wheels in the same axle possible.

5.1. Powertrain topology

In the current market, there are few powertrain systems categorized by power source, which combining them with different drivetrain components, can give birth to thousands of different powertrain configurations.

- **Conventional**. These are systems that use an internal combustion engine (ICE) to drive the vehicle combining it with a transmission and final drive [16]. There are two kinds of ICE: the spark ignition engine (SI engine) and the compression ignition engine (CI engine), also known as gasoline and diesel engines [17].
- **Electric**. These kinds of powertrains are powered by electricity. In comparison with conventional powertrains, electric ones are propelled by electric motors and do not need a reducer, simplifying the transmission system [18].
- **Hybrid**. Hybrid vehicle powertrains are a mix of conventional and electric vehicle powertrains. This system was designed in order to extract the benefit of each system previously commented, the energy density of gasoline and the efficiency of electric motors [18].

5.1.1. Which powertrain is the most convenient for an Amphibious vehicle?

The selection of the best powertrain system is a key point to design the powertrain. In order to clarify which system is the most suitable for the weather in the North Pole, a brief research should be done, comparing advantages and inconveniences of conventional and electric powertrains.

EV		Conventional	
Pro	**Cons**	**Pro**	**Cons**
No direct gas emissions	Lower fuel energy density	Higher fuel energy density	Air pollution
Low noise emissions	Long time to recharge the batteries	Quickly fuel refuelling	Irregular mass distribution
Low consumption cost, low price kWh	Vehicle price	Larger range	Waste of energy
Lower maintenance costs	Lower range	Vehicle price	More space needed due to the engine and fuel tank
Efficiency >90%		Efficiency 25-35%	More noise emissions
Instant torque, offer maximum power from the standstill			Maximum power achieved at a specific engine speed
Smooth power delivery, achievable at any moment			Irregular power delivery
Uniform mass distribution			
Energy conservation			
Less space needed			
Possibility to become energy independent using renewable energy			

Table 1. Comparison EV and Conventional Vehicles [19] [20] [21]

Once we have made a comparison and seen the results, it is obvious that the most suitable powertrain is the electric one due to all of its advantages. Despite the few disadvantages showed in Table 1, currently, the state-of-the art of this kind of powertrain is improving so fast that they have almost reached the specifications of the conventional vehicles through Lithium-ion batteries, fast chargers, etc.

There is no doubt that electric vehicles are the future since they are much more efficient and produce less emission, helping the environment. For this reason, nowadays, electric vehicles are getting more popular in the cities. Nevertheless, this fact is not happening in cold places. Therefore, we are wondering: why are electric vehicles not popular in cold weather places?

Lithium-ion batteries (LIBs) are able to work in a temperature region from -20ºC to 60ºC, the optimal range being 15ºC to 35ºC. Once the temperature is out of the working region, these batteries will degrade fast, leading to an increase of safety problems such as the risk of fire and explosion [22].

As stated by Z.G. Qu et al. [23], decreasing the battery cell temperature from 20ºC to -20ºC, the battery capacity is reduced an 88% with respect to the original capacity at 20ºC due to the plating by the lithium deposit on the anode surface during the charging process. Moreover, plating could induce an internal short circuit in the battery, resulting in serious safety issues. This means that low temperatures affect the performance of all the electric vehicles.

In spite of many heating strategies to warm up the battery under cold weather conditions [23], this area is still being studied since the actual state-of-the art of the battery heating is not totally effective and should be optimized. Therefore, the best option for the North Pole would be a conventional powertrain using a CI engine which is more efficient than the SI engine.

5.2. Conventional powertrain components

In this section, the main elements of the powertrain will be briefly explained.

5.2.1. Engine

The prime mover of the powertrain, better known as Engine, is a machine with the purpose of converting energy from some kind of fuel into mechanical energy. In the current market, the most popular engines are the internal combustion engines (ICE), which have two different ignition types: Spark-Ignition (SI), also known as Gasoline engine, and Compression-Ignition (CI), also known as Diesel engine. Nevertheless, in the past few years, electric engines are gaining more importance in the automotive market because of the improvement in the capacity of batteries, although it is still worse than ICEs.

5.2.2. Power take-up elements

In conventional powertrains, the engine is always running (when turned on), even when the vehicle is stopped. Therefore, in order to allow the engine to start and run without moving the vehicle, a device is needed to connect and disconnect the engine power from the transmission. This device is also needed in manual gearboxes, since the transmission should not spin during gear changes. Depending on the type of gearbox, manual or automatic, a clutch or a torque converter will be used, respectively.

5.2.2.1. Dry-plate friction clutch

The friction clutch is composed by a pressure plate, a clutch disk and the engine's flywheel. The flywheel and the pressure plate are connected to the output of engine's crankshaft, while the clutch disk is connected to the beginning of the transmission shaft.

In order to transfer rotational speed and torque from the engine to the transmission, the flywheel and pressure plate are engaged to the clutch disk though a central spring plate. Otherwise, to disengage the clutch, a force is applied to the center of the pressure plate, through mechanical or hydraulically actuated throw-out bearing, releasing the pressure [15].

5.2.2.2. *Wet-plate friction clutch*

The wet-plate friction clutch compared to the dry-plate one, has the advantage that its thermal performance is better because the oil has a higher heat dissipation capacity. Sometimes, the wet clutch also has space-saving advantage, since some friction-drive gear-shift component could be used for the power take-up process. Nevertheless, the drag losses of the wet-plate are higher than the dry-plate friction clutch [15].

5.2.2.3. *Hydrodynamic torque converter*

The hydrodynamic torque converter, composed by an impeller, a turbine and a stator, compensates the speed difference between the drivetrain and the engine. The impeller converts the mechanical energy into fluid energy, through the oil of torque converter, and later it is transformed back into mechanical energy, through the blades within the turbine.

This take-up power element has the advantage that it eliminates vibration peaks and absorbs vibrations effectively. However, it is useless for motor-vehicle applications due to its conversation range and efficiency at high levels of slip. Hence, it is only useful when it is combined with multi-speed or continuously variable gearbox [15], which will be explained in the next section.

5.2.3. Transmission (Gearbox)

The vehicle's transmission, also called gearbox, is the drivetrain element in charge of converting the engine's power and torque to make it able to run up the vehicle from the stationary state and once it is running, transform the speed to be able to break the vehicle's resistance forces such as the aerodynamic resistance, the rolling resistance, or the climbing resistance.

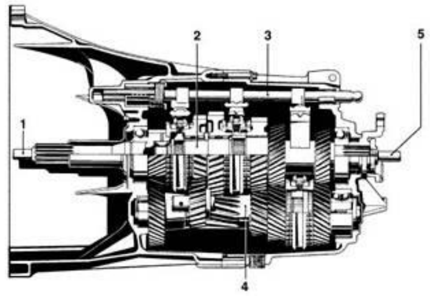
Multi-speed gearboxes are very popular in motor vehicles due to their efficiency, optimal adaptation to the vehicle's traction and they are an easily mastered technology. Gear shifting in these gearboxes is performed by a disengagement of power transmission (manual and semi-automatic gearboxes) or under load by a friction mechanism (automatic gearboxes) [15].

The manual-shifted transmissions installed in passenger cars and in heavy vehicles, are usually a dual-shaft transmission, with main and countershaft (idler shaft), in order to optimise the space. However, in heavy commercial vehicles, it is not unusual to find a transmission with more than two shafts [15].

Automatic transmissions are usually planetary transmissions (Ravigneaux or Simpson planetary gears) and the countershaft designs are barely used [15].

5.2.3.1. *Manual transmission*

Manual transmissions are composed basically by a variable-ratio gear transmission unit and a shift mechanism with a shift lever controlled by the driver. The layout of the gearbox depends on the vehicle's drive configuration (front-wheel drive, rear-wheel drive, 4-wheel drive) [15]. An example of 5-speed gearbox with conventional drive layout is shown in Figure 20.



1. Input shaft
2. Main shaft
3. Selector rail
4. Idler shaft
5. Output shaft

Figure 20. 5-speed transmission [15]

5.2.3.2. *Automatic transmissions*

As it is mentioned previously, there are two types of automatic transmissions [15]:

- Semi-automatic transmissions are manual gearboxes on which shift actions are carried out by an electronic system instead of the action of the driver.
- Fully automatic transmissions. This gearbox, unlike manual transmissions, allows the gear shifting while the power of the engine continues being transmitted to the driving wheels.

The main factor which determines the type of transmission that will be installed in one vehicle is the vehicle's handling dynamic, e.g., in the case of the off-road vehicle. Usually fully-automatic transmissions are also used in cases where the disengagement of the engine-transmission power has a serious impact on the driving comfort. Nevertheless, semi-automatic transmissions are used in conventional vehicles like passenger cars, trucks, racing cars, etc.

5.2.3.2.1. Fully automatic transmissions

In the case of fully automatic transmission, which is always accompanied by a hydrodynamic torque converter, the gear's change operation does not need an action executed by the driver.

This kind of transmission is composed by a hydrodynamic torque converter, a number of planetary gears, a hydraulically-actuated multiplate clutches, plate or band, one-way clutches, a transmission-control system and an engine-driven hydraulic-fluid pump [15].

Compared to the manual and semi-automatic transmissions, the fully automatic transmission has a lower efficiency, but it is compensated by shift programs designed to keep the engine in the optimum work range promising the minimum fuel consumption.

5.2.3.3. Continuously variable transmission (CVT).

The CVT is able to convert every point on the engine's operating curve into an operating range within the driving conditions requirement. The advantage of this kind of transmission is its potential to enhance the performance and fuel economy while at the same time reducing the exhaust emissions [15].

The CVT can operate in different ways, mechanically, hydraulically or electrically. Currently, the most used one is the mechanical continuously variable transmission employing steel belts due to its high level of development achieved. The main elements that compose this CVT are an engagement mechanism for starting off, a primary and secondary disk with axially adjustable taper-disk sections, an electronic/hydraulic transmission control, the reversing mode and the final drive unit with differential.

5.2.4. Differential

In the driving process, there are a lot of different phenomena that can affect the vehicle's dynamic. There are cases, such as variations in the road surface, that produce different coefficient of friction at the respective wheel making them, sometimes, roll with different speed. Another scenario is when a vehicle is cornering, there is always a difference in the speed between inside and outside wheels [15].

In order to allow these discrepancies in the respective rotation rates of the drive wheels, there is an element called Differential which makes it possible for the wheels to roll in different speeds and consequently, a vehicle equipped with differential, the wheels of the same axle are able to roll independently from each other.

5.2.5. All-wheel drive transfer case

As it is known, all-wheel drive (AWD) vehicles have a better behaviour on slippery surfaces and rough terrain than rear-wheel drive (RWD) or front-wheel drive (FWD) vehicles.

The difference between AWD and RWD or FWD is that the first one is equipped with a transfer case that propels speed and torque at the same time to the rear and front differential. Commonly, the torque distribution between front and rear axles are 50:50 coming from the transmission, although there are different distributions [15].

Currently, there are two systems available: dis-engageable all-wheel drive and permanent all-wheel drive.

5.3. Powertrain configurations

The configurations explained in the following part are different possibilities that may be considered for a North Pole Amphibious Vehicle.

5.3.1. Four-wheels drive powertrain

Being a sort of All-Terrain Vehicle, the most important feature is the vehicle traction on the road since this will allow the vehicle to overcome different kinds of terrains. It is clear that our main options are all-wheel drive vehicles.

The first choice is a four-wheel drive powertrain (Figure 22), where the engine propels power to front and rear wheels though a transmission, a transfer case and driveshafts.

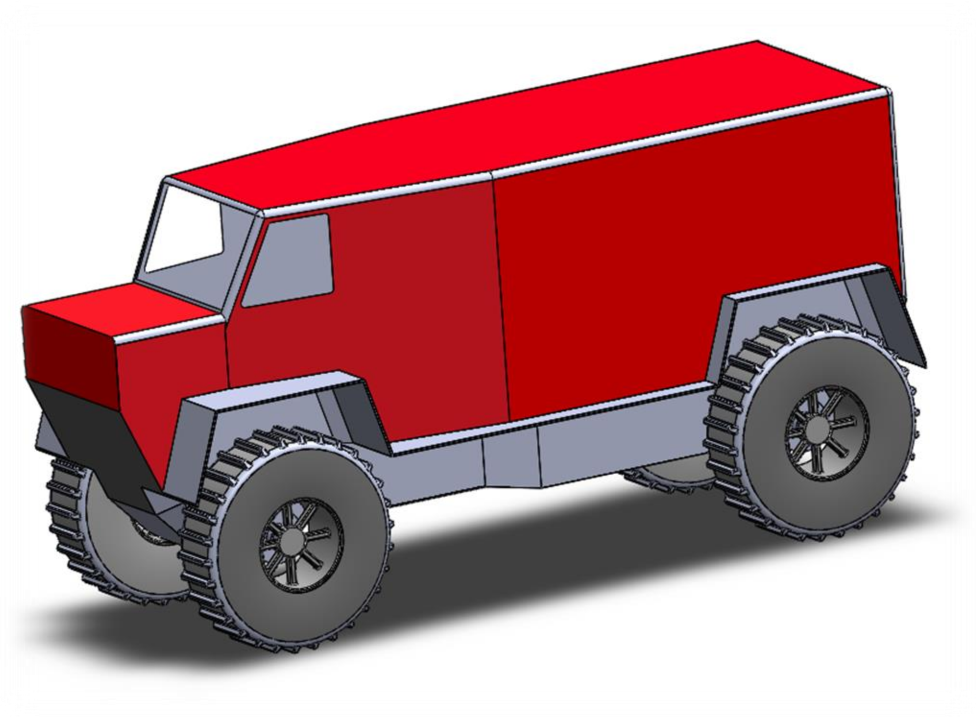


Figure 21. Four-wheels vehicle body

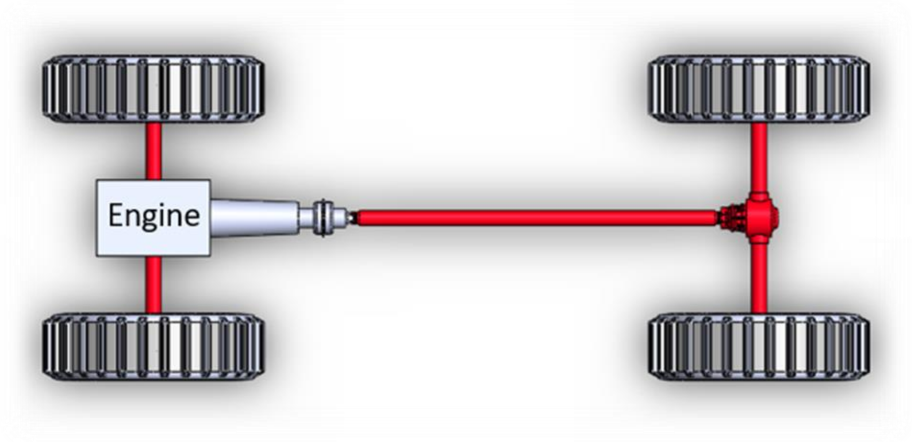


Figure 22. Four-wheels powertrain

5.3.2. Six-wheels powertrain

The second option is a six-wheels drive powertrain (Figure 24). Unlike the first choice, this powertrain is equipped with another transfer case that transmits power from the middle axle to the rear axle.

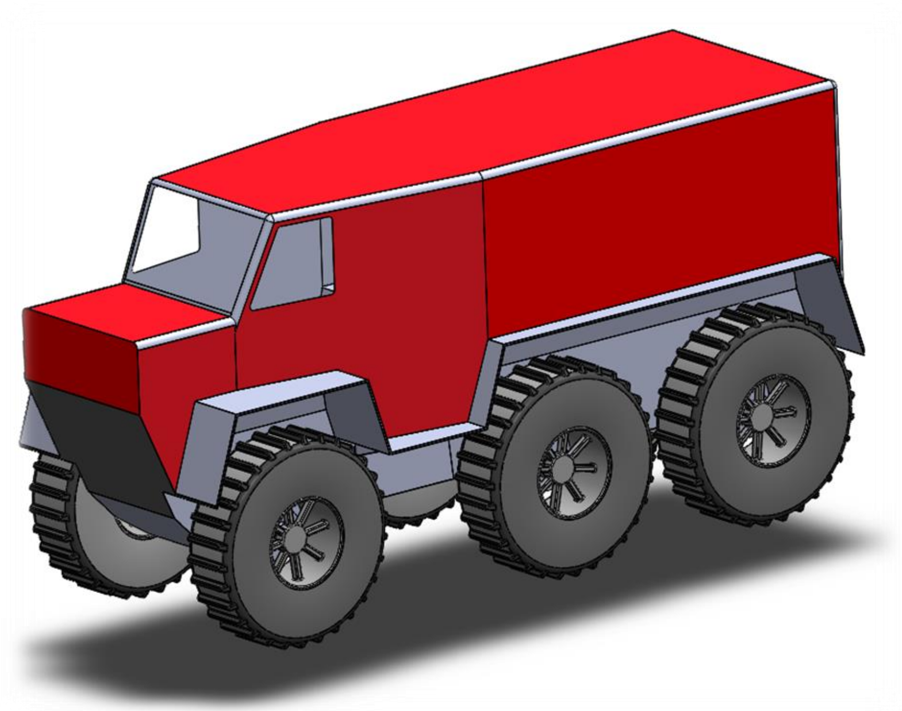


Figure 23. Six-wheels vehicle body

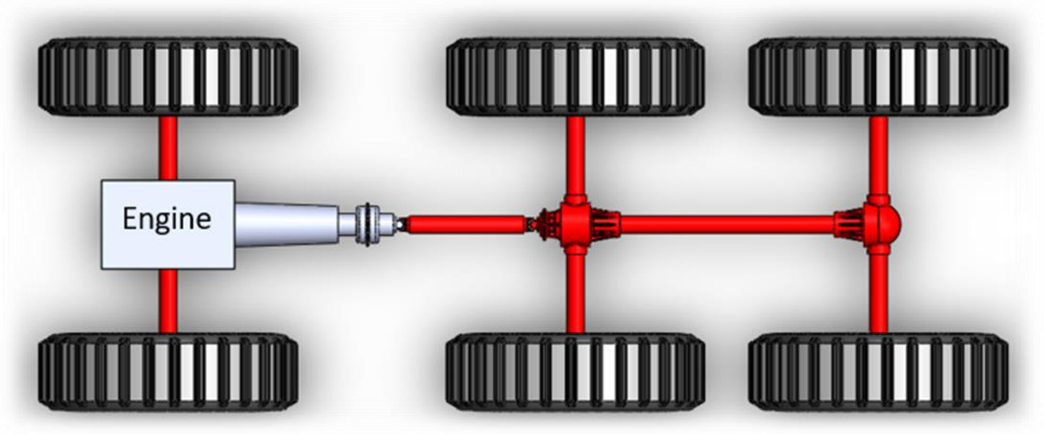


Figure 24. Six wheels powertrain

6. Powertrain modelling

Once we know the requirements of the amphibious vehicle and its powertrain system, it is time to proceed to perform the simulation of the Powertrain in order to analyse how the different components will interact once all are combined. This simulation will consist in analysing the behaviour of all the powertrain's components assembled in conjunction, as a complete system, from the engine, through the driveline, until the drive wheels.

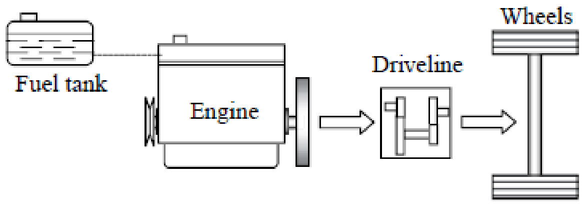


Figure 25. Simple powertrain scheme [16]

Currently, there are two methods to simulate vehicles and its components. These are the Quasistatic approach and the Dynamic approach.

- Quasistatic approach. In quasistatic simulations, the input variables are the vehicle speed and acceleration, and the road grade angle [24]. Through these variables, the fuel consumption could be obtained following the chart shown in Figure 26.

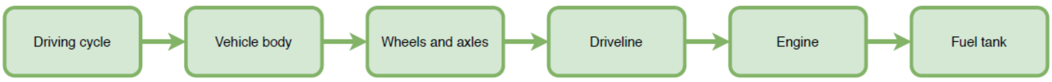


Figure 26. Quasistatic conventional vehicle model

- Dynamic approach. Dynamic simulations are based on the mathematical description of the systems. The inputs in this method are the same signals as those presented in a real propulsion system. Unlike the first method, in this one there is a block that emulates the behaviour of the driver, which makes the simulation much more complicated [24].

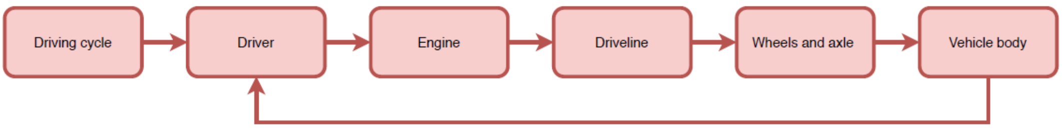


Figure 27. Dynamic conventional vehicle model

Nowadays, there are many ways to build a vehicle simulation. They can be created by using numerical computing programs or specific programs designed just for this purpose. Some examples are:

- **QSS toolbox**. This toolbox is a set of blocks to use in Simulink. QSS toolbox is an educational library made by Guzzella [24], with simple quasistatic models of vehicles component.

- **ADVISOR**. Advanced Vehicle Simulator is a set of models, data, scripts, etc. designated with Matlab and Simulink. ADVISOR allows to design and analyse conventional, electric and hybrid vehicles rapidly by combining different powertrain components.
  This simulator is able to analyse the performance of vehicles and their fuel consumption using data measured in laboratories [25].

- **DYMOLA-MODELICA**. Dymola is a complex tool designed to model and simulate systems of aerospace, automotive, robotic and process sectors. Modelica is a library used in Dymola, which contains a large number of components, in order to design different systems. This tool allows us to simulate vehicles powertrain, study the behavior of the vehicle on the road and also the cooling system for the engine or electric batteries [26].

- **MATLAB**. Matlab is a numerical computing environment used by millions of engineers and scientists, allowing them to carry out complex iterative analysis. Therefore, knowing the components dynamics of a vehicle, it could be easy to simulate its behavior by coding the dynamics in Matlab.

  Matlab provides different tools. One of them is Simulink which allows to design based on mathematical models. Simulink offers a library known as Powertrain Blockset, where we can find the main components models designed by Matlab developers.

  Another tool offered by Matlab is Simscape, this lets us quickly create physical system models in Simulink. With Simscape we can also model complex systems such as vehicles powertrain [27].

In this thesis, Matlab-Simulink is going to be used since it is a software that provides an educational license. Moreover, Matlab offers many examples, teaching how to model different types of powertrain easily and also offers the Powertrain Blockset, where there are many components already modelled.

6.1. Components

IC Engine

As explained in section 5.1.1, for the North Pole Amphibious Vehicle, the best option is a Diesel engine, since Diesel has the best energy density, which allows the vehicle to have a larger autonomy.

In the vehicle powertrain analysis, the engine characteristics are very important in order to obtain an accurate performance. Due to the complexity of modelling a full engine, another option has been used to simulate the engine, which is using look-up tables indexed by the angular speed and torque obtained by different tests made by a dynamometer [16], as it is shown in Figure 28. However, there are not many maps available freely in the literature, leading researchers to use old engine maps [28].

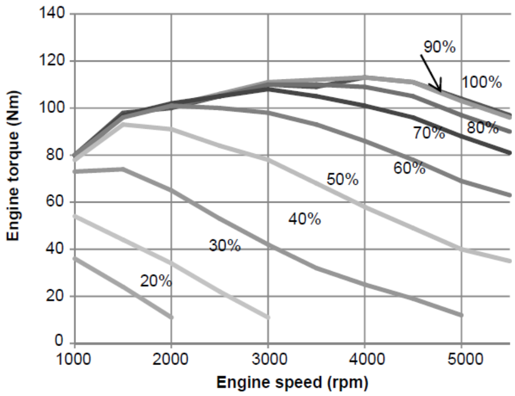


Figure 28. 2-D Throttle map of engine [16]

In Simulink Powertrain Blockset there are different engines previously modelled. In this project, the CI engine will be used:

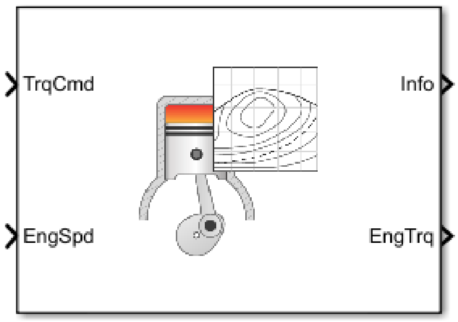


Figure 29. Mapped CI Engine [27]

Mapped CI Engine block is a set of several Look-up tables where inserting the required torque and engine speed, the block calculates parameters as the engine torque, engine speed, engine fuel flow output, etc. This block is totally configurable, it allows the modification of every value that defines an engine e.g. number of cylinders, crack revolutions per power stroke, total displaced volume.

Transmission

As previously commented in section 5.2.3., the use of gearbox is a must in conventional vehicles since this allows the engine speed and torque to match with the vehicle's load and speed conditions.

The Gearbox is nothing else than several meshed gears with the following kinematic [16]:

$$r_s = \frac{\omega_o}{\omega_i} \quad (6.1)$$

$$r_T = \frac{T_o}{T_i} \quad (6.2)$$

$$P_i = T_i\omega_i = P_o = T_o\omega_o \quad (6.3)$$

Being,

ω_o, ω_i: The output and input rotational speed.

T_o, T_i: The output and input torque

r_s, r_T: The speed and torque ratios, respectively. These ratios are defined by the number of gear teeth of the input and output gears. These ratios also provide the relation between the input and output speed and torque.

P_o, P_i: The output and input powers.

Simulink Powertrain Blockset offers various transmissions previously modelled. In the case of this thesis, an Ideal fixed gear transmission is going to be used, accompanied by a transmission shift logic made in Stateflow in order to simulate an automatic gearbox.

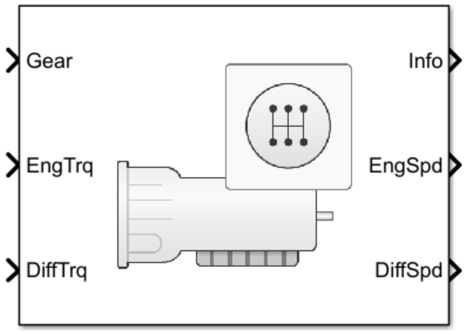


Figure 30. Ideal fixed gear transmission [27]

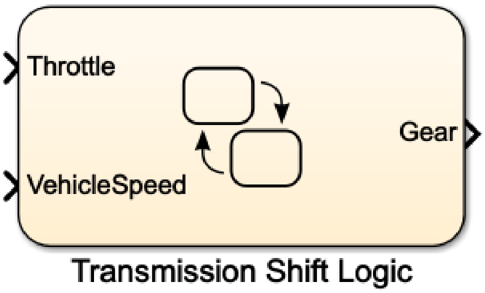


Figure 31. Transmission shift Logic [27]

Introducing the gear number to engage, applied input torque and applied load torque in the Ideal fixed gear transmission block, this returns as result the output angular speed. Like every block from the Powertrain Blockset, this one is completely configurable, allowing us to modify the efficiency, the gear ratios, the number of gears, etc.

Stateflow enables us to code the shifting algorithm using states which, by reading the throttle and the speed of the vehicle, could define the optimum gear instantly in that moment. Figure 32 shows a shift logic made for a six gears transmission.

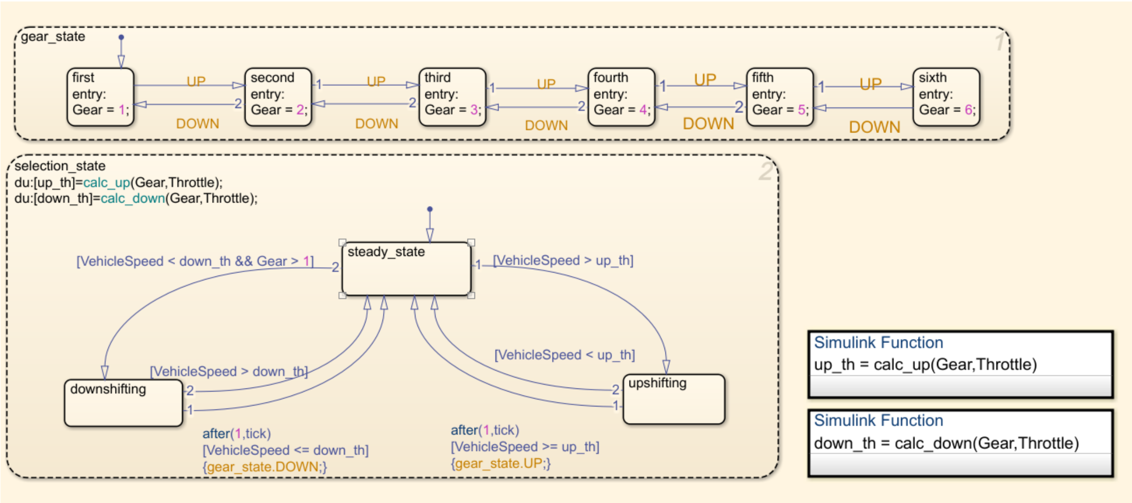


Figure 32. Transmission shift logic Stateflow [29]

All wheel drive transfer case

The transfer case is a common component in all AWD vehicles. This mechanism allows to split a single input shaft into two output shafts.

In Simulink Powertrain Blockset, there is the Split Torsional Compliance that implements the following schematic and equations [27].

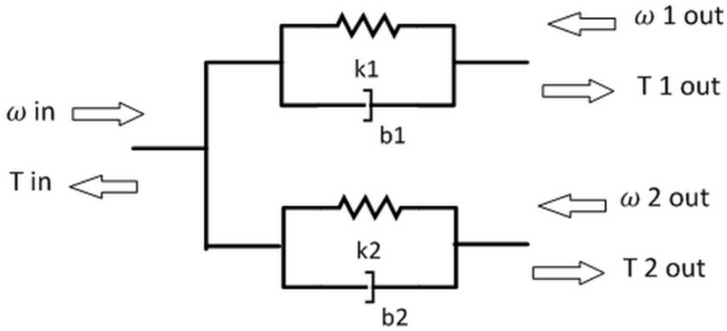


Figure 33. Split torsional compliance schematic [27]

$$T_{in} = -(\omega_{in} - \omega_{1out})b_1 - (\omega_{in} - \omega_{2out})b_2 - \theta_1 k_1 - \theta_2 k_2 \tag{6.4}$$

$$T_{1out} = (\omega_{in} - \omega_{1out})b_1 + \theta_1 k_1 \tag{6.5}$$

$$T_{2out} = (\omega_{in} - \omega_{2out})b_2 + \theta_2 k_2 \tag{6.6}$$

$$\dot{\theta}_1 = (\omega_{in} - \omega_{1out}) \tag{6.7}$$

$$\dot{\theta}_2 = (\omega_{in} - \omega_{2out}) \tag{6.8}$$

Being:

T_{in}: The applied input reaction torque.

ω_{in}: The input shaft rotational speed.

T_{1out}, T_{2out}: The applied torque to first and second shaft.

$\omega_{1out}, \omega_{2out}$: The rotational speed of the first and second output shaft.

b_1, b_2: First and second shaft viscous damping.

k_1, k_2: First and second shaft torsional stiffness.

Obtaining a block that links the input shaft speed, first and second output shaft speed with the input shaft torque, first and second shaft torque, as shown in Figure 34.

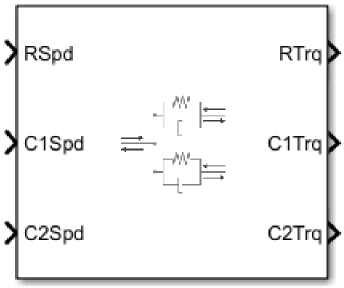


Figure 34. Split torsional compliance [27]

Driveshaft

In real vehicles, it is not possible to connect all the powertrain components without a bridge since there are long distances that separate some of these mechanisms. This is why driveshafts exist, used to assembly different mechanisms as the gearbox with the differential.

Powertrain Blockset supplies a block called Torsional compliance (Figure 35) to simulate the driveshaft. This block enables the calculation of the input torque and the load torque just introducing the input angular velocity and the load torque angular velocity.

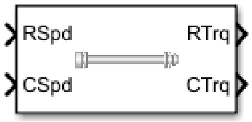


Figure 35. Torsional compliance [27]

Differential

As explained in section 5.2.4, modern vehicles are equipped with differentials in order to allow the rotational speed discrepancies of the drive wheels from a same axle produced by the variation of the road surface or when the vehicle is cornering.

The differential (Figure 36) is just a set of gears assembled in a way that permits the left and the right axle to rotate in different velocities.

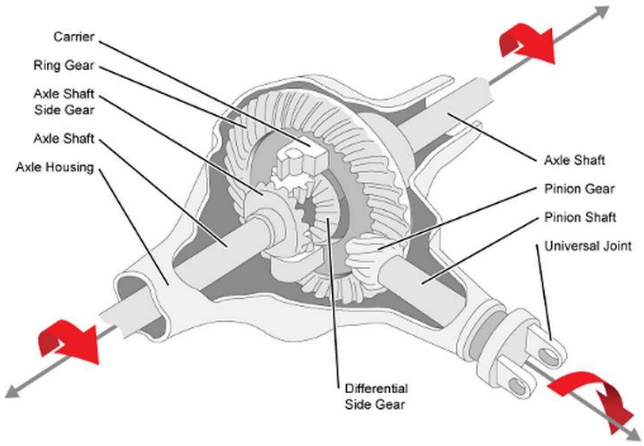


Figure 36. Open differential [27]

The equations to represent the dynamic response of this mechanism are [27]:

$$\dot{\omega}_d J_d = T_d - \omega_d b_d - T_i \quad \text{Ring Gear} \quad (6.9)$$

$$\dot{\omega}_1 J_1 = T_1 - \omega_1 b_1 - T_{i1} \quad \text{Left axle} \quad (6.10)$$

$$\dot{\omega}_2 J_2 = T_2 - \omega_2 b_2 - T_{i2} \quad \text{Right axle} \quad (6.11)$$

$$T_1 = T_2 = \frac{N}{2} T_i \quad (6.12)$$

$$\omega_d = \frac{N}{2}(\omega_1 + \omega_2) \quad (6.13)$$

Being,

N: Carrier to drive shaft gear ratio.

J_d: Rotational inertia of the ring gear.

b_d: Ring gear linear viscous damping.

ω_d: Drive shaft angular speed.

J_1, J_2: Axle 1 and axle 2 rotational inertia.

b_1, b_2: Axle 1 and axle 2 linear viscous damping.

ω_1, ω_2: Axle 1 and axle 2 angular speed.

T_1,T_2: Axle 1 and axle 2 torque.

T_i: Drive shaft internal resistance torque.

T_{i1}, T_{i2}: Axle 1 and axle 2 internal resistance torque.

All these equations results in the open differential block (Figure 37) which provides the angular speed of the driveshaft and angular speed of the output axles from the driveshaft torque and the output axles torque.

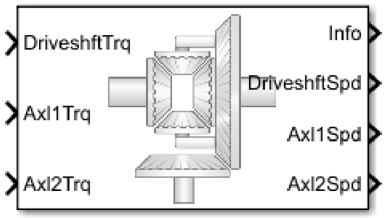


Figure 37. Open differential [27]

Drive wheel

The vehicle's tire is one of the most complex systems to model since it describes the interaction of the longitudinal force between the tire and the road [30]. In this thesis, the semi-empirical tyre model called *Magic Formula* is going to be used, a model that uses a single equation to describe the longitudinal forces and the tire transient behaviour. Due to the complexity of this single equation and its relatives, the equations will be not explained since these could be found in the literature *Tyre and Vehicle Dynamics* by Hans B. Pacejka [31] and have already been modelled by Matlab developers.

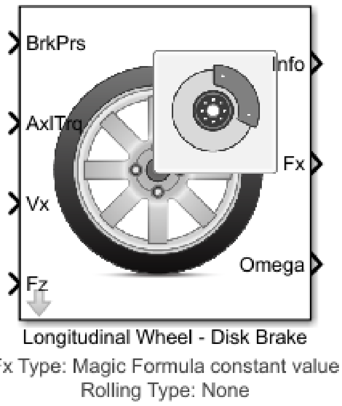


Figure 38. Longitudinal wheel - Disk brake [27]

The longitudinal wheel block has as input the brake pressure, input axle torque, lineal speed and the normal force. With these inputs the block is able to calculate the wheel angular speed, the longitudinal axle force, among other variables.

6.2. Vehicle

The main goal of this simulation is to model the powertrain and see how it works. However, just simulating the powertrain components is not enough because the automatic transmission needs to know the vehicle speed in order to perform the gear shift. Therefore, the vehicle should be modelled.

To model the vehicle, the one degree-of-freedom (DOF) vehicle model will be used in order to simplify the process.

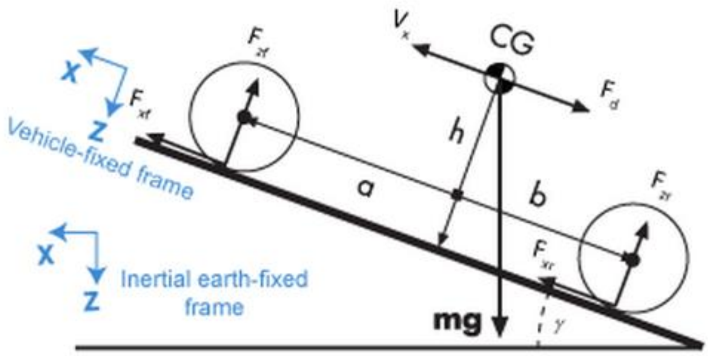


Figure 39. 1D vehicle dynamics [27]

The longitudinal model of the 2 axles vehicle is based on the rigid vehicle body dynamics as shown in Figure 39 and it is described by the following equations [27]:

$$m\dot{V}_x = F_x - F_d - mg \cdot \sin\gamma \tag{6.14}$$

$$F_x = N_f F_{xf} + N_r F_{xr} \tag{6.15}$$

$$F_d = \frac{1}{2} C_d \rho A (V_x + V_w)^2 \cdot sgn(V_x + V_w) \tag{6.16}$$

$$F_{zf} = \frac{-h\left(F_d + mg\sin\gamma + m\dot{V}_x\right) + b \cdot mg\cos\gamma}{N_f(a+b)} \tag{6.17}$$

$$F_{zr} = \frac{+h\left(F_d + mg\sin\gamma + m\dot{V}_x\right) + a \cdot mg\cos\gamma}{N_f(a+b)} \tag{6.18}$$

$$N_f F_{zf} + N_r F_{zr} = mg\cos\gamma \tag{6.19}$$

Being,

F_{xf}, F_{xr}: Longitudinal forces on front and rear wheel at the ground contact point, respectively.

F_{zf}, F_{zr}: Normal load forces on front and rear wheel at the ground contact point, respectively.

V_x: Vehicle speed.

V_w: Wind speed.

N_f, N_r: Number of wheels on front and rear axle, respectively.

γ: Angle of road grade.

m: Vehicle mass.

a, b: Distance from CG to front and rear axle, respectively.

h: Height of CG above the axle plane.

C_d: Frontal air drag coefficient.

A: Frontal area.

ρ: Air mass density.

g: Gravitational acceleration.

This model is already modelled in Matlab Powertrain Blockset (Figure 40), where, introducing the longitudinal force on front and rear axle, the road grade and the wind speed, we can obtain the vehicle speed and the front and rear axle normal force among other signals.

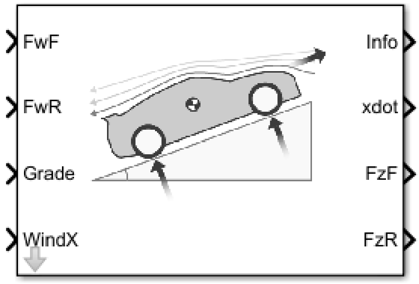


Figure 40. 1-DOF vehicle [27]

3 Axles vehicle longitudinal dynamic model

There is a big difference between two and three axles vehicles. The former can be defined as a statically determinate (isostatic) structure, whereas the latter is always considered as a statically indeterminate (hyperstatic) structure [32].

The cause of why 2-axles vehicles are isostatic and vehicles with more than 2 axles are hyperstatic is because each axle of a vehicle has a no-roll center (Q), that is to say, a 3-axles vehicle has three no-roll centers and a 2-axles vehicle has two no-roll centers, each at a different height. Those no-roll centers are united with a no-roll axis. Hence, when there are just two points, a straight line could be defined but not with three points [32], as it's shown in Figure 41 .

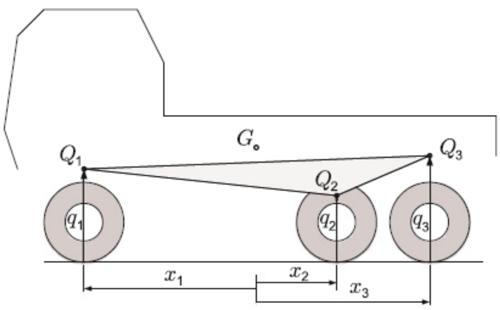


Figure 41. Vehicle no-roll centers and axles [32]

Therefore, the suspension and tire vertical stiffnesses are going to be used to solve the hyperstatic structure of three axles vehicles.

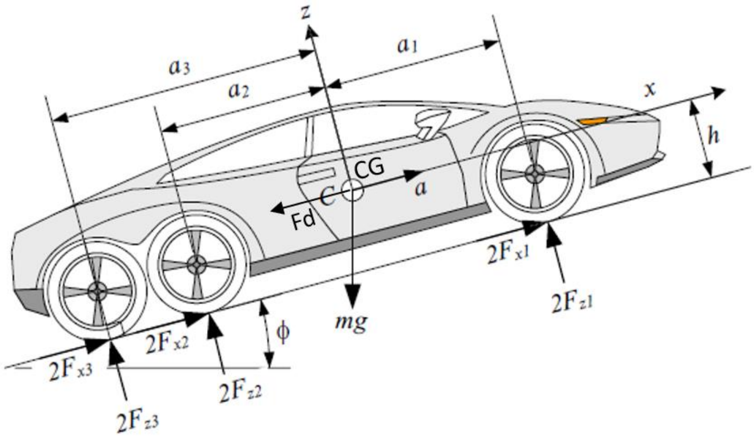


Figure 42. Three-axles vehicle with two wheels at each wheel [33]

The longitudinal model of the 3-axles vehicle is based on the rigid vehicle body dynamics, as shown in Figure 42, and it is described by the following equations [33]:

$$2F_{x1} + 2F_{x2} + 2F_{x3} - F_d - mg\sin\phi = ma \tag{6.20}$$
$$2F_{z1} + 2F_{z2} + 2F_{z3} = -mg\cos\phi = 0 \tag{6.21}$$
$$F_d = \frac{1}{2}C_d\rho A(V_x + V_w)^2 \cdot sgn(V_x + V_w) \tag{6.22}$$
$$F_{z1} = \frac{Z_1}{Z_0}k_1 m \tag{6.23}$$
$$F_{z2} = \frac{Z_2}{Z_0}k_2 m \tag{6.24}$$
$$F_{z3} = \frac{Z_3}{Z_0}k_2 m \tag{6.25}$$

Where, (6.26)

$$Z_0 = -4k_1k_2(x_1 - x_2)^2 - 4k_2k_3(x_2 - x_3)^2 - 4k_1k_3(x_3 - x_1)^2 \tag{6.27}$$

$$\begin{aligned} Z_1 = {} & g(x_2k_2 - x_1k_3 - x_1k_2 + x_3k_3)h\sin\phi \\ & + a(x_2k_2 - x_1k_3 - x_1k_2 + x_3k_3)h \\ & + g(k_2{x_2}^2 - x_1k_2x_2 + k_3{x_3}^2 - x_1k_3x_3)\cos\phi \end{aligned} \tag{6.28}$$

$$\begin{aligned} Z_2 = {} & g(x_1k_1 - x_2k_1 - x_2k_3 + x_3k_3)h\sin\phi \\ & + a(x_1k_1 - x_2k_1 - x_2k_3 + x_3k_3)h \\ & + g(k_1{x_1}^2 - x_2k_1x_1 + k_3{x_3}^2 - x_2k_3x_3)\cos\phi \end{aligned} \tag{6.29}$$

$$\begin{aligned} Z_1 = {} & g(x_1k_1 + x_2k_2 - x_3k_1 - x_3k_2)h\sin\phi \\ & + a(x_1k_1 + x_2k_2 - x_3k_1 - x_3k_2)h \\ & + g(k_1{x_1}^2 - x_3k_1x_1 + k_2{x_2}^2 - x_3k_2x_2)\cos\phi \end{aligned} \tag{6.30}$$

$$x_1 = a_1 \tag{6.31}$$
$$x_2 = -a_2 \tag{6.32}$$
$$x_3 = -a_3 \tag{6.33}$$

Being,

F_{x1}, F_{x2}, F_{x3}: Longitudinal forces on first, second and third wheel at the ground contact point, respectively.

F_{z1}, F_{z2}, F_{z3}: Normal load forces on first, second and third wheel at the ground contact point, respectively.

k_1, k_2, k_3: Suspension stiffness on first, second and third axle, respectively.

V_x: Vehicle speed.

V_w: Wind speed.

ϕ: Angle of road grade.

m: Vehicle mass.

a_1, a_2, a_3: Distance from CG to first, second and third axle, respectively.

h: Height of CG above the axle plane.

C_d: Frontal air drag coefficient.

A: Frontal area.

ρ: Air mass density.

g: Gravitational acceleration.

As a result, in Simulink, a block (Figure 43) where, inserting the longitudinal force of each wheel, returns the normal forces of each wheel and the speed vehicle at that exact moment.

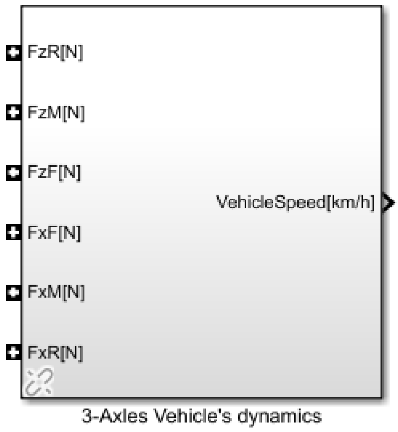


Figure 43. Three axles 1-DOF vehicle

6.3. Simulation

Once every system of the powertrain is modelled, it is time to put them all together in Simulink in order to simulate the two options described in section 5.3. The current section is completed by taking as example some tutorials made by Matlab developers [29].

Many parameters of the vehicle used in these simulations are the parameters provided by Matlab because, as explained in section 6.1 (engine simulation data), there are not enough data offered by the literatures, neither by the supplier's catalogues. Thus, the easiest way to build a powertrain simulation is using old data acquired in laboratories used in previous simulations.

The simulations in this thesis will use Matlab data instead of old data from laboratories because the latter are usually obsolete in the current market since automotive sector changes quickly. Therefore, using obsolete laboratory data is exactly the same as using Matlab data. Moreover, the goal of this simulation is to identify which of the two proposed powertrains is the best option for the conditions in the North Pole. To identify the best option, the same engine, transmission, kind of wheel, etc. will be used in both powertrains, but changing the number of wheels, transfer cases, vehicle masses and every parameter involved in adapting the vehicle from 4WD to 6WD.

On the other hand, the 3D CAD vehicle designed with Solidworks (Figure 44) [34] could provide some useful data for the simulation on Simulink, e.g. the drag force and the vehicle frontal area.

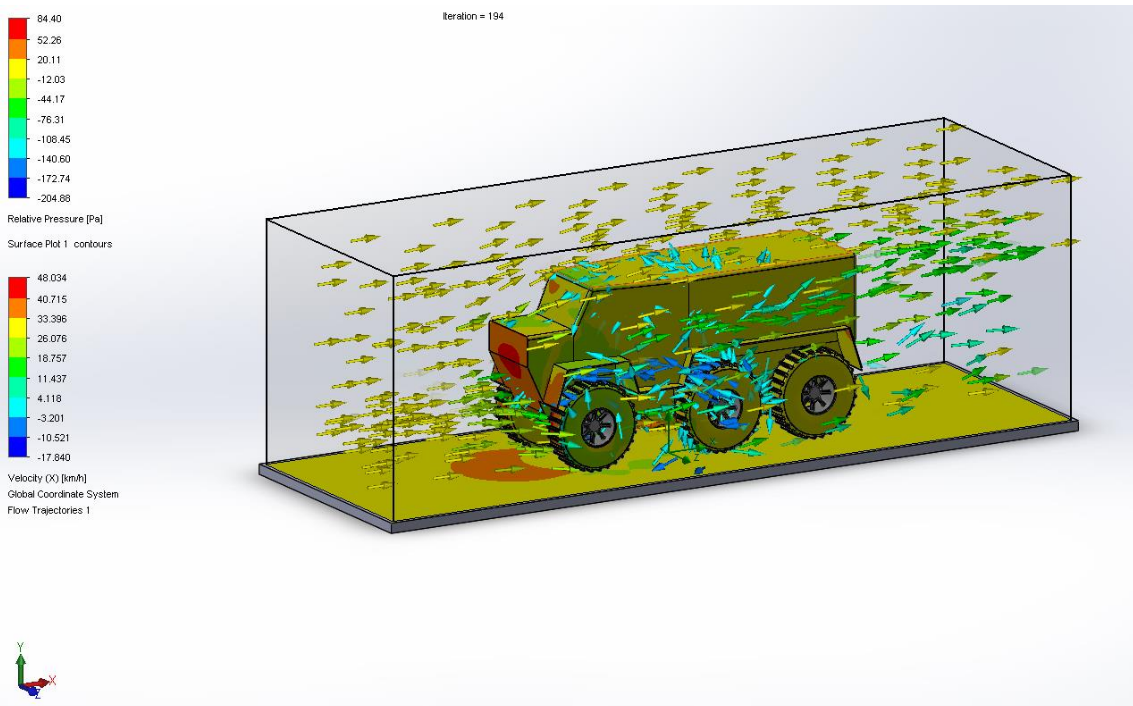


Figure 44. Vehicle flows trajectories

The drag coefficient C_d is defined as:

$$C_d = \frac{2F_d}{\rho v^2 A} \tag{6.34}$$

Where,

F_d: Drag force.

ρ: Mass density of the fluid.

v: Flow speed.

A: Reference area.

Via Solidworks, it is known that the average drag force is 241.433N, the flow speed is 30km/h, the vehicle front area is 6.94m^2 the fluid mass density is 1.457 kg/m^3, temperature is -31ºC. Consequently, through the equation 6.34, we can calculate the drag coefficient, obtaining $C_d = 0.88$.

The vehicle mass is also calculable in Solidworks, but it is difficult to know the weight accurately because there is no information about the interior of the vehicle. Consequently, the Yemelya weight [11] is going to be used as example for the 6WD vehicle and adapted to the 4WD vehicle.

6.3.1. 4WD Powertrain

The four-wheels drive powertrain in Simulink is shown in Figure 45. As it is shown, the powertrain is composed by the engine (Figure 46), driveline (Figure 47), wheels & brakes (Figure 49) and the vehicle body (Figure 50).

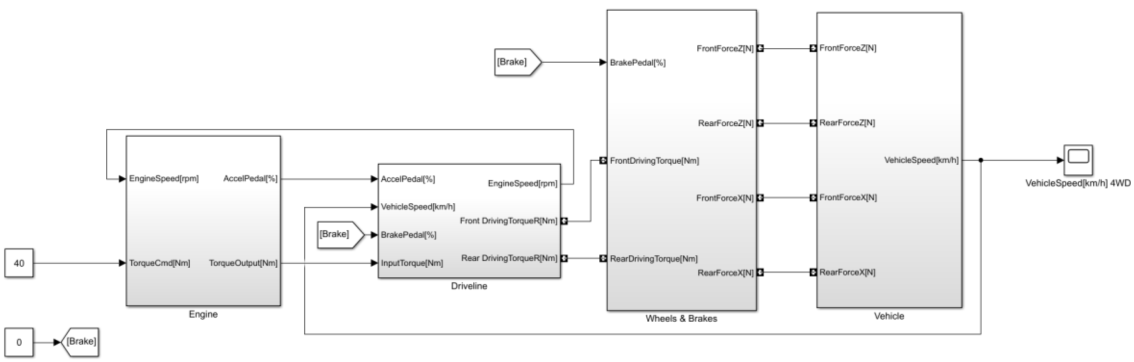


Figure 45. 4WD Powertrain

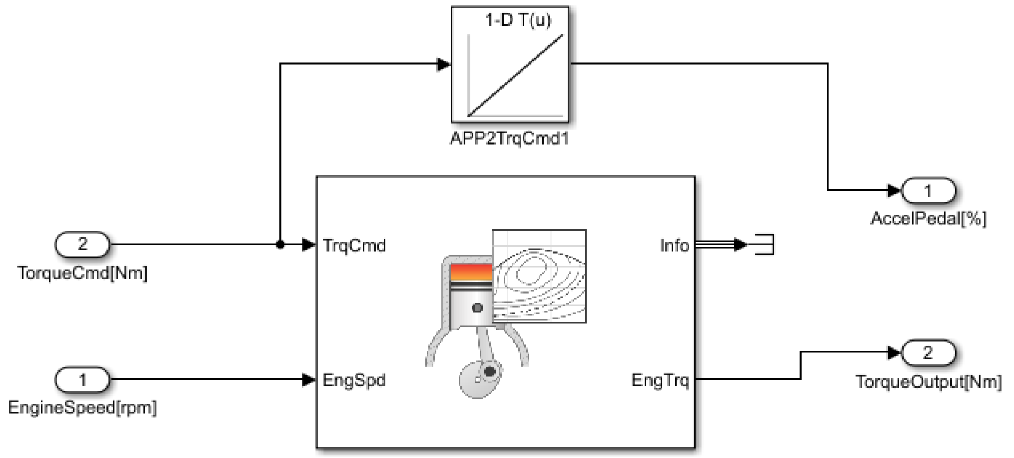


Figure 46. Engine subsystem

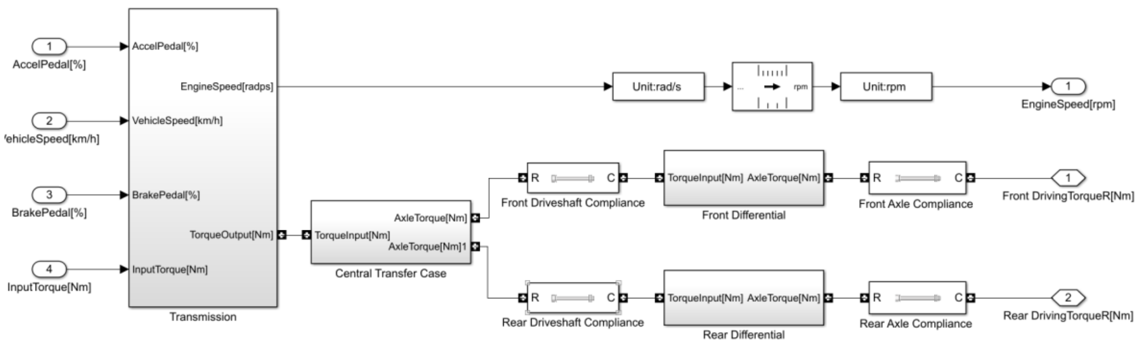


Figure 47. 4WD Driveline subsystem

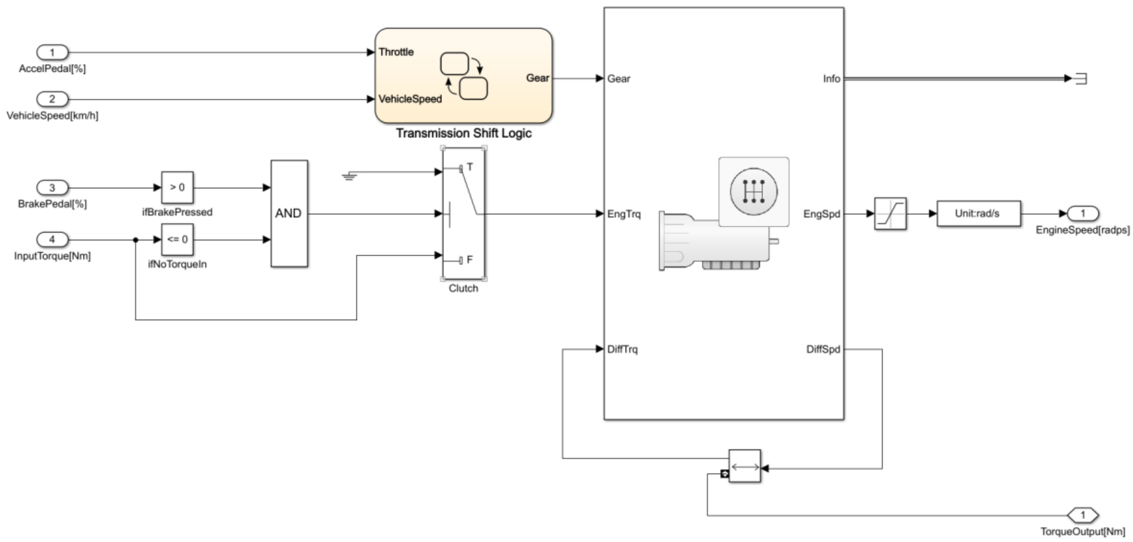


Figure 48. Transmission subsystem

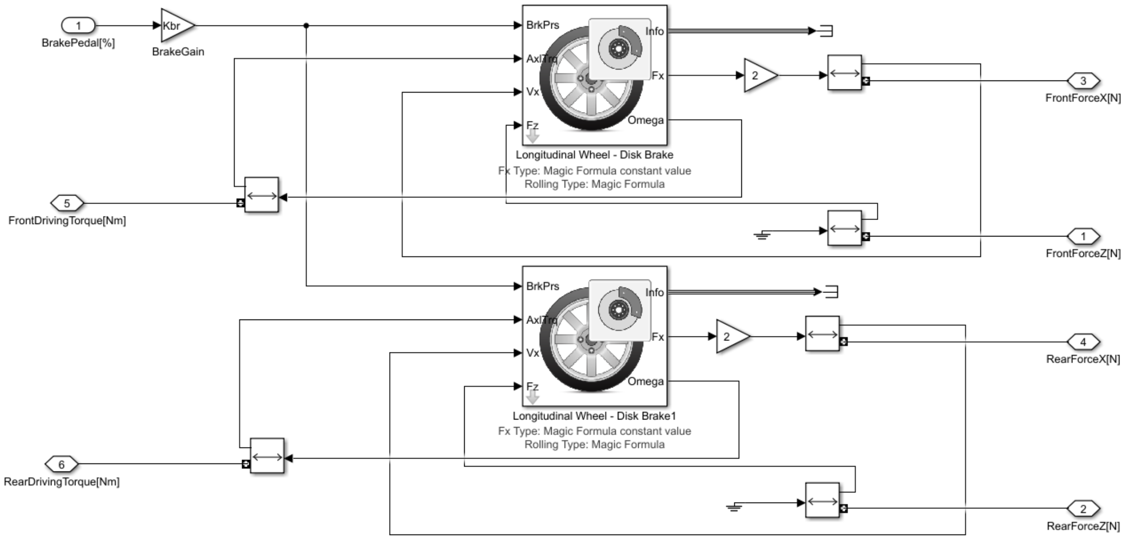


Figure 49. 4WD Wheels & Brakes subsystem

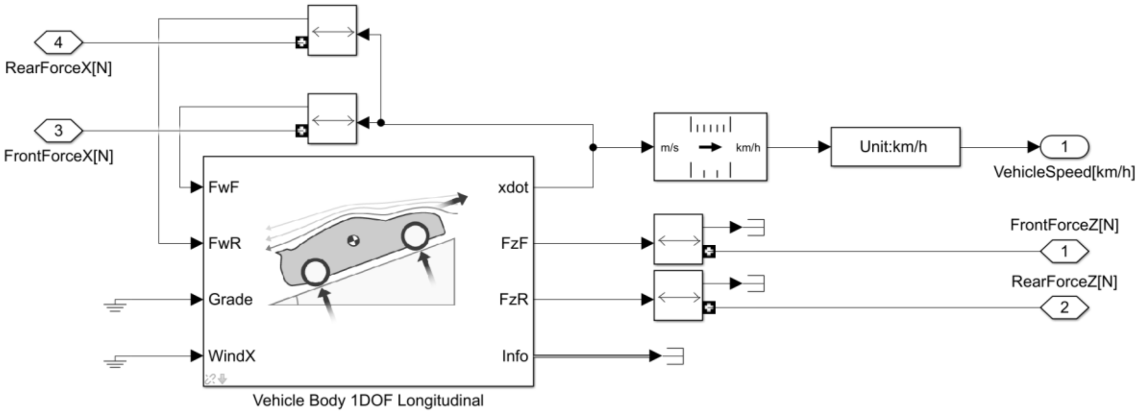


Figure 50. 4WD Vehicle subsystem

6.3.2. 6WD Powertrain

In this option, the powertrain is composed by two transfer cases and 6 wheels instead of one transfer case and 4 wheels like the first option.

The way to assembly this powertrain is exactly the same as the 4WD powertrain, as it is shown in Figure 51.

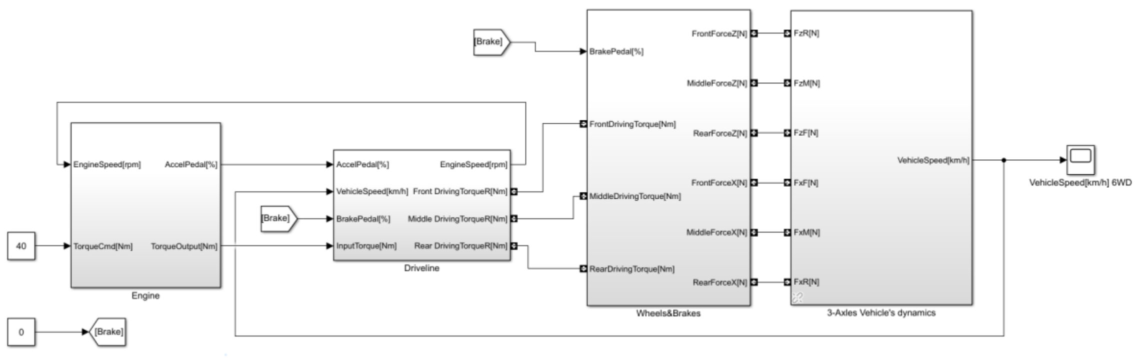


Figure 51. 6WD Powertrain

Although the assembly is the same, it is easy to detect that there are a few changes on the driveline, the wheels & brakes and the vehicle subsystems. The differences are shown in the following figures.

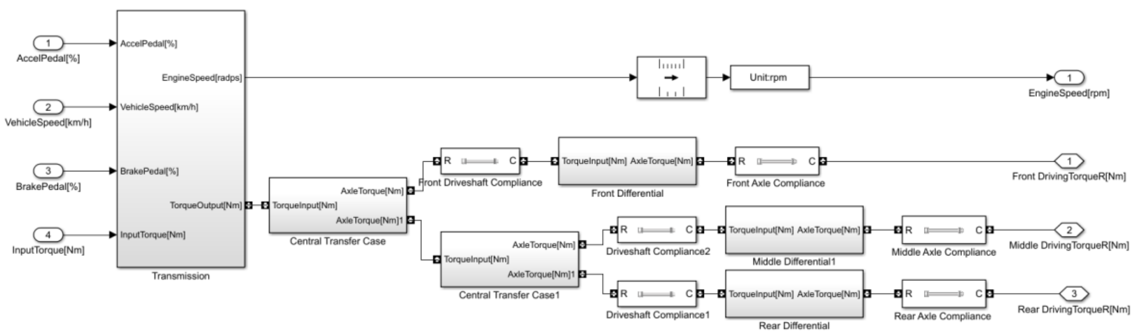


Figure 52. 6WD Driveline subsystem

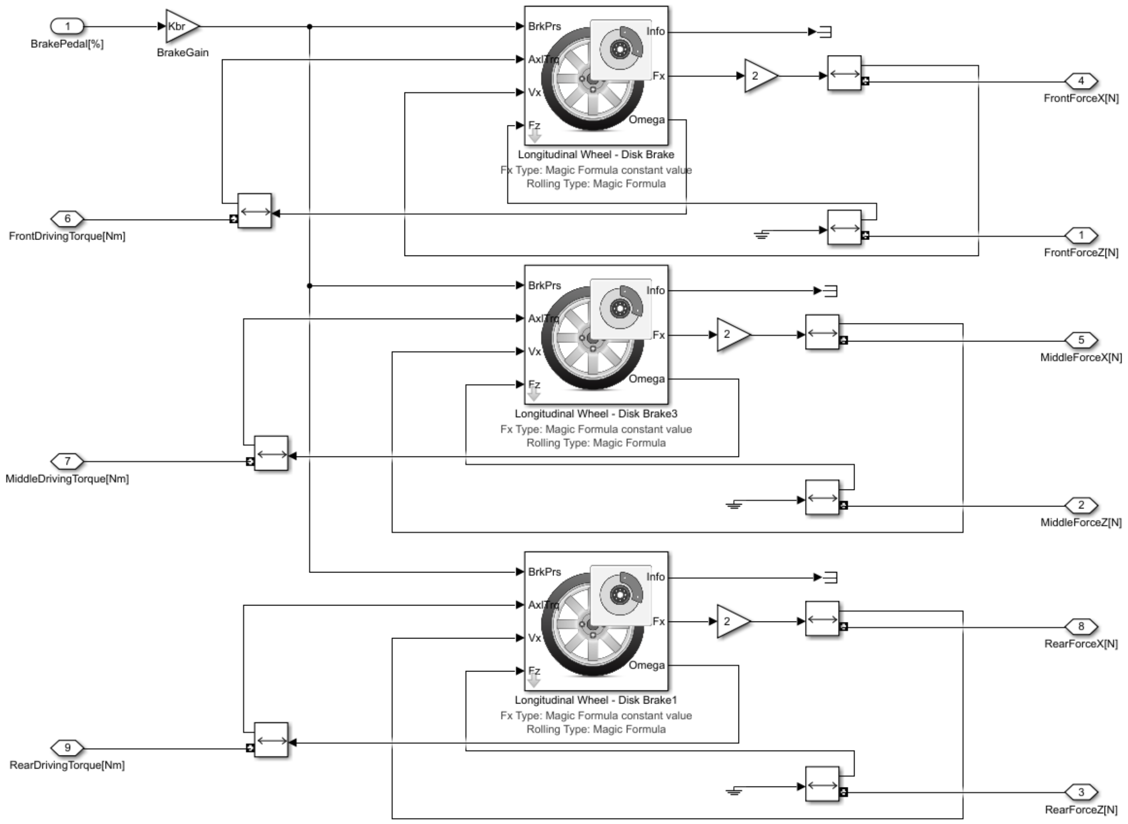


Figure 53. 6WD Wheels & Brakes subsystem

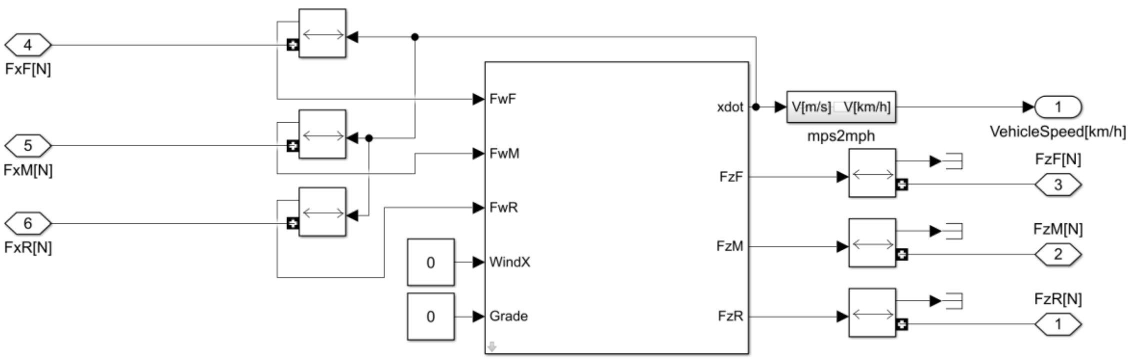


Figure 54. 6WD Vehicle subsystem

6.4. Results

The results obtained in the previous simulations, carried out in Simulink, are shown below.

Comparing the results, the 4WD powertrain (Figure 55) can reach a higher velocity than the 6WD powertrain (Figure 57) using the same conditions. The main cause of this difference of velocity is due to the weight of the six-wheel vehicle being much higher than the four-wheel vehicle.

On the contrary, the slip, shown on the vehicle speed scopes (difference between theoretical and real speed), indicate that the 6WD has better thrust, although there is not too much difference since the slip is produced in a short time period.

Last but not least, the normal force that each vehicle produces are quite different. The 4WD powertrain has a more uniform distribution than the 6WD powertrain, which means that the CG is positioned in a better place and the vehicle will have more stability over the water.

On the whole, the 4WD powertrain is more suitable than the 6WD, as the first one is more efficient, it is lighter and the vehicle will have more autonomy.

4WD Powertrain

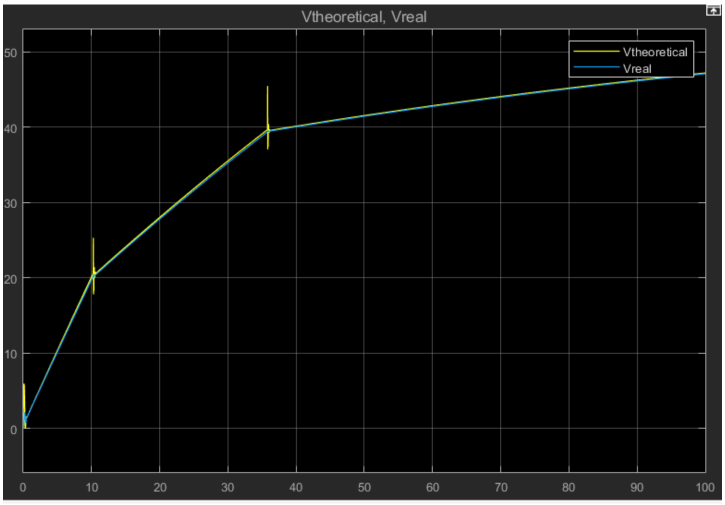


Figure 55. 4WD Vehicle speed [km/h] vs. time [s]

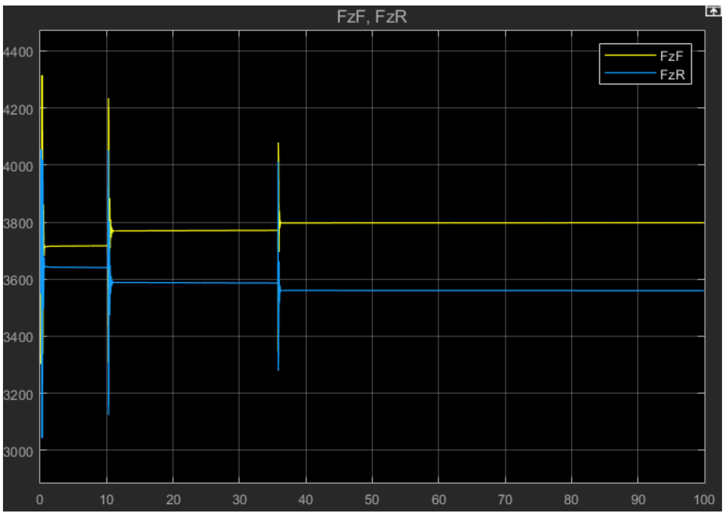


Figure 56. 4WD Normal force [N] vs. time [s]

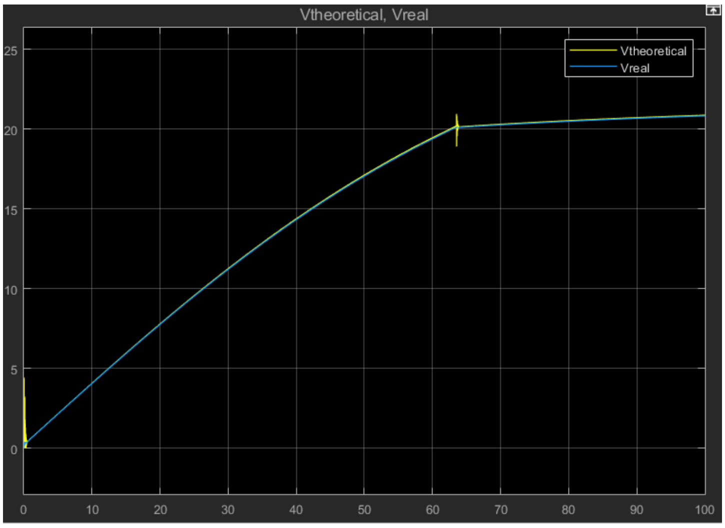


Figure 57. 6WD Vehicle speed [km/h] vs. time [s]

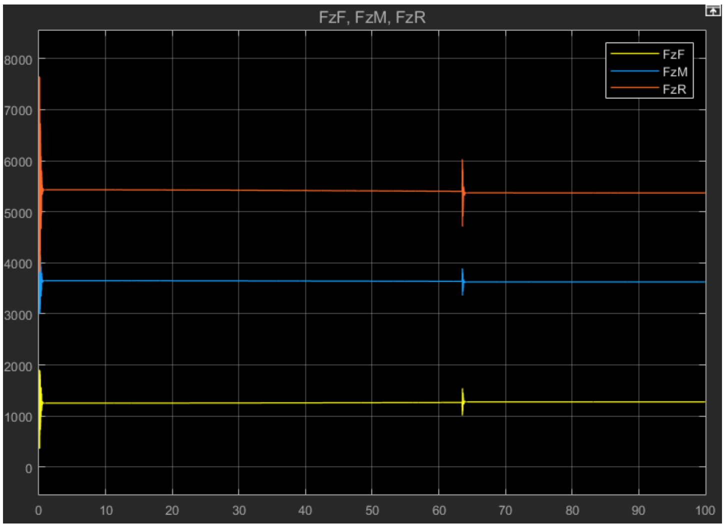


Figure 58. 6WD Normal force [N] vs. time [s]

7. Conclusion

In this project, the requirements to design an amphibious vehicle aimed to be used in the North Pole were stated, both the vehicle body and the powertrain requirements.

The results of the analysis indicate that this kind of vehicle body needs to be very resistant and watertight to avoid the corrosion and allow the buoyancy. Moreover, to allow the buoyancy, the vehicle should be manufactured with light material.

In other matters, the vehicle powertrain that is best fitted in the North Pole weather conditions is the conventional powertrain equipped with a diesel engine. This system offers a good performance in low temperature places and also the best driving range. The 4WD powertrain had the best results, in terms of efficiency, range and vehicle weight, obtained by the Simulink simulation, notwithstanding the 6WD shown a better thrust and less slip.

Once the research about the amphibious vehicle technologies and the powertrain analysis are finished, it is clear that the work done in this project is no more than a brief introduction because to design a whole vehicle, many resources are needed.

The powertrain simulation could be much more complex, adding electronic controllers, studying the behaviour of the powertrain changing the terrain conditions, such as hopping from ice to water. But the range of this master's thesis is not that wide to make such deep research.

However, this thesis proposes an innovative field of research not only to the automotive sector but also to the energy sector since, as stated in section 5.1.1, the current State-of-art is not enough to adapt an electric vehicle to work in these conditions. Moreover, this research could be very interesting for many countries, especially great powers like China, US and Russia, which are interested in the North Pole since the Global warming is opening new paths to the rest of the world.

As a personal conclusion, this project has provided new knowledge to the author like the vehicle dynamics, the powertrain simulation via Simulink and also the behaviour of lithium-ion batteries in cold temperatures. Learning all these was very gratifying because they were unknown fields of study for the author.

To sum up, this master's thesis helped the author to have a deeper knowledge about vehicles simulation, leading him to know how to model a vehicle and acquire knowledge of different modelling software available on the current market.

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